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A Quality Metric for Sustainable Innovations

Arcot Desai NARASIMHALU
Singapore Management University, desai@smu.edu.sg

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Arcot Desai Narasimhalu

Singapore Management University, 80 Stamford Road, Singapore 178902.
E-mail:Desai@smu.edu.sg

Abstract: Sustainability has become a major concern for nations and firms especially since the Kyoto Protocol was defined in 1997. While there have been several studies on benchmarks for national innovation systems and effectiveness of innovation management within firms there is as yet no reasonable metric for determining the quality of an innovation much less its quality relating to sustainability? Similarly, there have been several studies on sustainability but that such research groups have also not focused on developing a metric for denoting the quality of sustainable innovations. This paper offers a metric that defines the quality of an innovation, especially with regard to sustainability.

Keywords: Innovation; Quality; Metric; Sustainability.

1 Background

The phrase "sustainable innovations" can be interpreted in two different ways – innovations that will consume resources in a sustainable manner or sustainable processes for innovations that allow a firm to retain and improve its market leadership. We interpret and use the phrase "sustainable innovations" in the first context in this paper.

Innovation metrics have been studied extensively. Table 1 presents the progression of innovation metrics beginning the 1950s as adapted from [Milbergs and Vonortas]. The metrics for the fourth generation is still evolving and hence should not be considered to be final.

Table 1 Different generations of innovation metrics

Generation	First	Second	Third	Fourth
Period	1950s and 60s	1970s and 80s	1990s	2000 onwards
Metrics	Input indicators	Output indicators	Innovation indicators	Process indicators
Sample Individual Measures	R&D Expenditure, S&T personnel, Capital, Technology intensity	Patents, Publications, Products, Quality change	Innovation surveys, Indexing, Benchmarking innovation capacity	Knowledge, Intangibles, Networks, Demand clusters, Management Techniques, Risk return, System Dynamics

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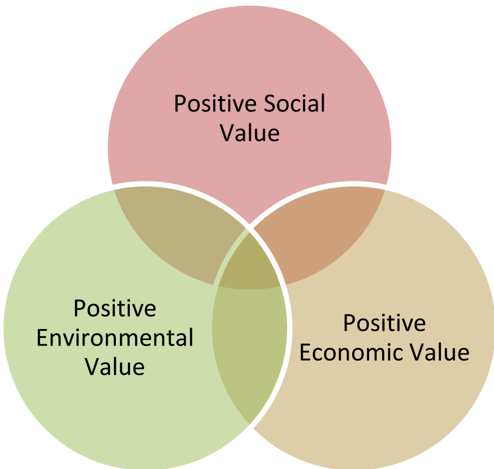
Sustainability has also been studied extensively. Figure 1 shows how sustainability lies at the intersection of responsible social, environmental and economic developments. Brundtland Report of 1987 [WCED] had defined sustainable development to be "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs." Sustainable innovations ought to comply with this definition. In this regard, Hansen, Grosse-Dunker and Reichwald [Hansen] introduced the concept of Sustainability-Oriented Innovations (SOI) as innovations which had a net positive effect on capital stock.

Figure 1 Positive values created by sustainable innovations in social, economic and environmental dimensions



Despite the well understood progression of innovations and the studies on sustainability including reports by powerful working groups on innovations such as the one headed by Nick Donofrio [National Innovation Initiative] did not identify sustainability as an important consideration in their 2004 recommendations for promoting innovations in the US or recommend a quality metric for sustainable innovations. However, some large companies such as Proctor and Gamble [Proctor and Gamble] have taken a multipronged approach at producing innovations in packaging and other areas that address sustainability. Even such companies are not known to use a quality metric to assess the value of their sustainable innovations. More recent works such as the book titled "Sustainable Innovation – The Organizational, Human and Knowledge dimension," by Rene Jorna [Jorna] or the academic publication on Sustainability Innovation Cube by Hansen, Grosse-Dunker and Reichwald [Hansen] have also not defined a quality metric for sustainable innovations.

Although one might argue the need for yet another metric for innovation or yet another paper on sustainability, it is our contention that there is as yet no well defined metric that can both help choose one innovation as more valuable than the others in the first place and to also evaluate its impact on sustainability.

In this paper, we first define a quality metric for an innovation in Section 2. Such a metric will help innovation managers compare innovations in order to identify the innovation with the best overall value. We then extend the quality metric to address sustainability in Section 3. Section 4 is devoted to a discussion on an example of possibly the largest industrial disaster that has and had deep implications for sustainability. Such disasters might perhaps have been averted if the innovators had access to a quality metric for sustainable innovations as described in this paper. We share our views on tradeoffs between economic value and sustainability in Section 5. Section 6 provides a summary and conclusions.

We realize that the quality metric defined in this paper is only a first step towards defining a robust quality metric for sustainable innovations. We invite and expect the innovation research community to refine our ideas in order to help innovation portfolio managers to select more profitable innovations from both economic and sustainability perspectives.

2 Quality metric for an innovation

In this section we present a quality metric denoted Qi for an innovation 'i'. The following are the definitions of parameters that we use to derive the quality metric of an innovation.

Let Pi be a pain or a craving for enhanced experience.

EPi - Extent of pain suffered by a community if the innovation was not available.

EPi can take on a normalized value ranging from 0 to 1. 1 will indicate extreme pain and 0 will indicate no pain. It is important to remember that the craving for enhanced experience, otherwise called ‘Pleasure’ can also be represented in a similar manner. An extreme craving for pleasure will take on a value of 1 and absolute lack of interest for enhanced experience will take on a value of 0. In other words, anything that is an acute need will take on a value of 1 and anything that is not attractive to customers will take on a value of 0. A ‘Want’ can take on a value ranging from 0.3 to 0.7 depending on how acute the ‘Want’ is.

Ni - Number of people suffering from Pi.

Ni represents that number of people who are either suffering from a pain or longing for an enhanced experience. The range will be from 0 to 6.5 billion (the population of the world).

DCi - The difficulty in copying / substituting / replacing an innovation.

DCi is the difficulty in copying the innovation. A value 0 represents that the innovation is easily copied and a value of 1 indicates that the innovation is extremely difficult to copy or replace. An innovation that can be copied in 3 weeks can be given a value of 0, one that takes between 12 to 18 months can be assigned a value of 0.5 and an innovation that will take several years to copy can be assigned a value of 1. The value of 1 can also be assigned to an innovation that is protected by a strong patent (that cannot be circumvented by another patent) given that it will ensure that others cannot copy the innovation during the life of the patent.

DMi - The difficulty in developing and marketing an innovation.

DMi will take on a value ranging from of 0 to 1. Innovations that are easy to develop will take on a value of 0 and those difficult to develop will take on a value of 1. Examples of easy to develop innovations are innovations in website design. Examples of difficult to develop and market innovations are those that are first to the world type of innovations. While innovative websites can be assigned a score close to 0 and designing a new automobile using same energy sources can be assigned a score closer to 0.4, innovations that require highly specialized knowledge for development can be assigned a score closer to 1. For example, developing cars that run on renewable energies can be assigned a score very close to 1 since this is a development that has not been widely practiced previously. One has to also realize that innovations addressing the needs of the market can be marketed more easily whereas the innovations meeting the wants of the market require much more advertisement and marketing dollars. This difference can be reflected in the values assigned for DMi.

Li - Life of the innovation

Li will take on a value ranging from 0 to n where n is the number of years the innovation is expected to be commercially exploited. Service innovations that are publicly visible will have a short life of a few weeks to a month whereas process innovations that are less publicly visible will have a life of twelve to eighteen months. Pharmaceutical products often have a life of several years.

AHi - Adoption hurdles faced by an innovation.

AHi will take on a value from 0 to 1. An innovation will have an AHi value of 0 if it is likely to face strong adoption hurdles and will have a value of 1 if it is not expected to have any adoption hurdle. Adoption hurdles are market segment sensitive and will take on different values in different markets. For example, some innovations that are good for the rest of the world may not be accepted in certain other markets. Innovations that might bear social, religious, moral, ethical and other taboos will have a higher adoption hurdle and hence will take a score closer to 0. Genetically modified crops faced a stiff adoption hurdle because the markets were not made aware of the experimental results from the tests on animals. This is an example of a societal adoption hurdle.

ASi - Assumptions index for the proposed innovation.

ASi will take on a value of 0 to 1. An innovation will take on an ASi value of 0 if the confidence factor across all its assumptions is 0 and will take on a value of 1 if the confidence that all its assumptions are solid and well founded. A good way of explaining this parameter is to examine the innovations arising out of market pull versus those created due to technology push. Technology push based innovations are quite often likely to take a value closer to 0 whereas market pull based innovations are more likely to take a value closer to 1. This is because most of the technology innovations are driven by blue sky research focused on longer term benefits and hence the inventors and innovators are likely to have made several assumptions that may not be true and may not have been validated in the market place. The market pull based innovations on the other hand would have identified the needs or wants of the market place and hence the assumptions behind the innovation will be more robust.

Once we have defined each of the above parameters, we can then calculate the quality metric of an innovation i, using the formula as presented in equation 1.

$$QMi = EPi * Ni * DCi * DMi * Li * AHi * ASi \quad \text{---- (1)}$$

There may be questions on how to determine the values for each of the parameters. It would be difficult to provide a standard set of table of values that anyone can use since these values could differ from firm to firm and from individual to individual within a firm. Hence, it is best that firms start with a standard set of values and evolve these values over time.

If PMi is the profit margin for the innovation i, then the economic value generated from innovation i, EVi, can be determined as per equation 2.

$$EVi = QMi * PMi \quad \text{---- (2)}$$

3 Quality metric for a sustainable innovation

We will now introduce an additional factor Si, for defining the quality metric of a sustainable innovation where Si is the sustainability index of an innovation.

Si, the sustainability index will carry a value between $-\infty$ and ∞, 1 being neutral. An innovation that creates significant negative value in all three dimensions, i.e. Social, Environmental and Economic, should be assigned a value closer to $-\infty$. An innovation that creates significant positive value in all the three dimensions should be assigned a value closer to ∞. An innovation that creates negative value in one or two of the dimensions should be assigned a value between $-\infty$ and 1. An innovation that creates marginal positive value in one or two of the dimensions should be assigned a value between 1 and ∞.

A simplistic assignment of weights is presented in Table 2. Table 2 and the triads listed therein are a sample set and should not be construed as comprehensive. One could also consider several other permutations of Marginal negative, Significant negative, Marginal positive and Significant positive in a more comprehensive table. Table 2 should be sufficient for the purposes of comprehending the discussions in this paper.

m1 to m8 and n1 to n8 are numerical values that represent the extent of value diminished or created by an innovation. Clearly, $m1 > m2 > \ldots > m7 > m8$ and $n1 > n2 > \ldots n7 > n8$. We can now define a quality metric for a sustainable innovation as given in equation 3.

Table 2 A sample set of weights for Si

Value created in the Social Dimension	Value created in Environmental Dimension	Value created in the Economic Dimension	Si
Significant Negative	Significant Negative	Significant Negative	-m1
Significant Negative	Significant Negative	Marginal Negative	-m2
Significant Negative	Marginal Negative	Significant Negative	-m3
Marginal Negative	Significant Negative	Significant Negative	-m4
Significant Negative	Marginal Negative	Marginal Negative	-m5
Marginal Negative	Significant Negative	Marginal Negative	-m6
Marginal Negative	Marginal Negative	Significant Negative	-m7
Marginal Negative	Marginal Negative	Marginal Negative	-m8
Neutral	Neutral	Neutral	1
Marginal positive	Marginal positive	Marginal positive	n8
Marginal positive	Significant positive	Marginal positive	n7
Marginal positive	Marginal positive	Significant positive	n6
Significant positive	Marginal positive	Marginal positive	n5
Marginal positive	Significant positive	Significant positive	n4
Significant positive	Marginal positive	Significant positive	n3
Significant positive	Significant positive	Marginal positive	n2
Significant positive	Significant positive	Significant positive	n1

QMSi = QMi * Si   ------ (3)

The sustainable economic value generated from an innovation i, can be computed according to equation 4.

EVSi = QMSi * PMi ----- (4)

The weights suggested in Table 2 is only a sample set. There are several issues to consider before arriving at the proper weights. For example, one should examine how to assign weights in situations such as when the economic importance of an innovation is so critical that one is willing to allow marginal negative impact on environmental factors. Detailed discussion on weighting in the context of such trade offs is beyond the scope of this paper. We realize that the approach suggested for assigning values to Si is but one of the several possible approaches.

4 An Example of impact due to lack of quality metrics for sustainable innovations

Manufacturing and processing of chemicals, metals, cement, and paper, mining, oil refining, fossil fuel reliant industries including coal fired power plants, airlines, automobile industry and factory farming are some sources of environmental pollution [China daily, Natural News, Wisegeek]. It may be surprising to realize that farm animals generate a great deal of methane, especially when they are raised in large numbers. When manure containers burst or fail they release pollutants on a large scale into the surrounding environment thus causing significant negative impact.

WHO has conducted studies on the impact of chemicals released arising from technological incidents [WHO]. The International Federation of Red Cross and Red Crescent Societies had estimated that a total of 100,000 people were killed and 1.5 million people were affected over a decade starting 2000, all these arising due to chemical incidents and natural disasters. Chemical incidents affect people through the effects of explosion, fire or toxic effects. Incidents such as the gas leakage at Bhopal, India in 1984 have captured world's attention. However, there are lesser known or reported incidents which cumulatively have had large negative health impacts [Bowen]. Significant economic costs arising out of such incidents relate to livelihoods, inward investments, and other costs such as closures of health care facilities, schools, factories, etc., litigation and compensation, and the cost of helping affected communities recover.

Let us take the Union Carbide plant that was built in India. It was clearly an innovation, at least an incremental innovation that was meant to address pesticide needs of the farmers in India. Union Carbide India, a subsidiary of Union Carbide Corporation had set up a pesticide plant near the city of Bhopal in the Indian state of Madhya Pradesh [Bhopal]. A leak of Methyl Isocyanate on the nights of December 2nd and 3rd of 1984 adversely affected hundreds of thousands of people and the incident was labeled as the worst industrial catastrophe at that time. Claims of death of human beings ranged from 2,259 to 15,000 and more than 500,000 people had suffered from temporary and permanent injuries. In February of 2011 the supreme court of India had issued a notice to Union Carbide and Dow Chemicals to pay a compensation of almost US$ 1.75 trillion to the victims of this disaster. Had Union Carbide known the economic price it would have to pay for the vulnerabilities of the plant, it could have invested in innovations that could have managed or minimized the impact of the gas leakage.

In this example the values for Si for the gas processing plant, an innovation, appear to be negative in the Social dimension, negative in Environmental dimension and positive in the Economic dimension at first glance. Let us explain. Union Carbide might have considered this plant as having positive economic impact such as creating jobs and also supplying pesticide that could increase the agricultural output leading to increased economic activity for the region. It is also possible that Union Carbide might have considered the probability of a leakage to be very little or very remote. However, it is not clear that they had anticipated the death toll and the amount of compensation that they may have to end up paying to the families of the victims of this disaster. Availability of a quality metric for sustainable innovation such as the one described in this paper might have alerted them about the extent of future compensations to be paid to the potential the victims of even a very remote incident. This realization might have perhaps resulted in a plant with additional safeguards. It turns out that in the end even the economic impact was negative taking into account the compensation to be paid, the number of lives lost or people injured, the number of jobs lost and the opportunity cost of the absence of economic activity.

5 Trades offs and revised Quality Metric for Sustainable innovations.

The example discussed in section 4 clearly highlights the fact that sometimes individuals or firms creating innovations such as the Union Carbide plant at Bhopal might honestly not be aware of the negative impacts on the economic, social and environmental dimensions. The innovators might not have created such innovations if they had some idea of the overall negative impact of even the potentially low probability events. Hence it would be useful to modify the quality metric for sustainable innovations to reflect the vulnerability, probability and impact of negative incidents.

Any innovation i, can be examined from the following three perspectives:

1. Residual vulnerability RVj, of an innovation to an incident j that can result in negative impacts on social, economic and environmental dimensions. RVj can take a value from 0 to 1, where 0 implies no vulnerability and 1 implies certain vulnerability to a negative incident.
2. Probability PRVj that the incident j will occur during the life of the innovation. PRVj will assume values between 0 and 1. A value of 0 for PRVj will imply that the probability of occurrence of the incident j is zero and a value of 1 will imply that the occurrence of the incident j is certain.
3. IRVj is the anticipated impact arising out of the incident j, from the economic, environmental or social dimensions. Although the impact could be along any of the three dimensions, it would be useful to translate the impact along environmental and social dimensions into monetary terms thus maintaining economic dimension to be the reference dimension for ease of ascertaining the quality metric of an innovation.

The value of a negative impact NVj due to an incident j, can then be derived as a function of RVj, PRVj and IRVj. A sample function is shown in equation 5.

$$NVj = RVj * PRVj * IRVj \quad \text{------ (5)}$$

Let us assume without any loss of generality that there can be '*l*' likely negative incidents associated with an innovation i. The Total Negative Value that could be generated by these incidents collectively can be represented as given in equation 6.

TNVi = for innovation i ----- (6)

A function involving TNVi can be used as Si in Table 2 described in Section 3. One could argue that an innovation is worth pursuing if the condition in equation 7 is satisfied.

$$EVi >> k^* \ TNVi \text{ for the ith innovation ----(7)}$$

Where $1 < k < \infty$

A revised Si, RSi could then be defined as shown in (8)

$$RSi = EVi + k*TNVi \text{ ----- } (8)$$

Revised QMSi, RQMSi and Revised EVSi, REVSi are defined in equations 9 and 10.

$$RQMSi = QMi * RSi \text{ ----- } (9)$$

$$REVSi = RQMSi * PMi \text{ ----- } (10)$$

How much should the value of k be and how much greater should the EVi be as compared to TNVi is the key question for the consideration of either the individual or the firm planning to commercialize an innovation. That decision will depend on whether the innovation under consideration is a MUST HAVE innovation for the survival of the human and other living species on this planet. There could be situations where the survival of a species in the near future might be considered to be of considerably greater importance than the total negative value created by an innovation. Such situations are not easy to deal with but they need to be addressed in any case.

6 Summary and conclusions

We presented the background and motivation for a quality metric of a sustainable innovation in Section 1. A quality metric for an innovation was defined in Section 2 and was then modified in Section 3 to include sustainability related considerations. Section 4 discussed the case of Union Carbide plant at Bhopal in Madhya Pradesh India as an example of an innovation that could have taken sustainability into their design considerations. We then discussed the trade offs between sustainability and near term considerations in Section 5.

We have not seen similar a quality metric for sustainable innovations defined in literature before. The reviewers of our abstract had mentioned that there existed some quality metrics. It is a pity that they did not give specific references that could have helped better shape our thinking and the quality of the paper. We hope to continuously search for the said references and modify our own recommendations for the quality metric for sustainable innovations to be aligned with the past work.

We also hope that this paper will provide a springboard for the advancement of our understanding of the quality metric for sustainable innovations. This is only the beginning and not the end of the search for an acceptable quality metric for sustainable innovations.

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